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HIGH TEMPERATURE AND PRESSURE TRIAXIAL COMPRESSION TESTS ON SAMPLES FROM BOREHOLE ATK1

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by

R. Jackson*

INTRODUCTION

High temperature, high pressure triaxial testing was conducted on samples obtained from borehole ATK1 in the Eye Dashwa Lake plutonic formation. Samples originated from a depth of 660.540 m to 664.430 m and are generally described as grano-dioritic. For a more detailed modal analysis see Technical Report 8081-T2 of the Nuclear Waste Disposal Program (1).

For a complete outline of the testing procedure and data analysis see CANMET Division Reports ERP/MRL 80-102(TR) and ERP/MRL 82-11(TR) (unpublished) (2). This report presents the experimental data, analysis and a brief description of the effects of temperature and confining pressure on triaxial strength, tangent modulus of elasticity, cohesive strength and angle of internal friction.

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FAILURE CHARACTERISTICS

The predominant mode of failure was a violent brittle fracture along a single diagonal failure plane. Considerable fragmentation occurred and the occasional bottom wedge or partially formed bottom wedge failure was noted.

Where single diagonal failure planes resulted, the failure angles ranged from 60° to 76°. The observed mean failure angle was 68.9° with a standard deviation of 5.0°, and variance of 23.0°. A comparison of observed failure angles and those predicted by the Mohr-Coulomb analyses are contained in Table 1.

Table 1 - Comparison of predicted and actual failure angles: Atikokan Granite

Temperature (°C)	Containing pressure (MPa)	θ Predicted	θ Actual	$\Delta\theta$
21	3.5	75.0°	71.0°	-4.0°
	17.0	73.5°	60.0°	-13.5°
			69.0°	-4.5°
	35.0	65.0°	60.0°	-5.0°
			70.0°	+5.0°
100	3.5	76.5°	72.0°	-4.5°
	17.0	70.5°	71.0°	+0.5°
	35.0	67.5°	72.0°	+4.5°
			64.0°	-3.5°
			67.0°	-0.5°
200	3.5	75.5°	76.0°	+0.5°
			76.0°	+0.5°
	17.0	72.0°	65.0°	-7.0°
			73.0°	+1.0°
	35.0	64.0°	71.0°	+7.0°
			65.0°	+1.0°

The average difference between the predicted and actual failure angles was 3.9°.

The Mohr-Coulomb analyses for each temperature range are contained in Fig. 1, 2 and 3.

EFFECT OF CONFINING PRESSURE AND TEMPERATURE ON TRIAXIAL STRENGTH

As expected, the Atikokan granite showed an increase in strength with confining pressure at all temperature levels. At a confining pressure of 3.5 MPa, essentially the same strength was exhibited at each temperature. The ambient temperature tests (21°C) showed the largest strength increases over the entire confining pressure range. Both the 100°C and 200°C exhibited successively smaller increases over the same confining pressures ranges (Fig. 4). Table 2 depicts the normalized strength changes with confining pressure and temperature. Experimental data scatter for the three temperature levels are illustrated in Fig. 5, 6 and 7.

Table 2 - Triaxial strengths normalized to 21°C and 3.5 MPa confining pressure

Confining pressure (MPa)	Temperature (°C)		
	21	100	200
3.5	1.00	0.99	1.00
17.0	1.62	1.56	1.53
35.0	2.04	1.95	1.87

As stated earlier, there was virtually no change in strength at a confining pressure of 3.5 MPa with increasing temperature. As the temperature increased, small decreases in strength were noted at confining pressure of 17.0 and 35.0 MPa. At 17.0 MPa, a 4% decrease was observed from 21° to 100°C and 2% from 100° to 200°C. The 35.0 MPa confining pressure exhibited decreases 3% and 2% respectively for the same temperature ranges (Fig. 8).

EFFECT OF CONFINING PRESSURE AND TEMPERATURE ON THE TANGENT MODULUS OF ELASTICITY

The tangent modulus of elasticity exhibited very different behaviour with increasing confining pressure at the various temperatures. At ambient (21°C), the modulus increased 27% as confining pressure increased from 3.5 to 17.0 MPa. However, from 17.0 to 35.0 MPa the modulus increase was only 1%. Results of tests at 100°C show a slight increase in modulus (1%) with confining pressure in the range 3.5 to 17.0 MPa. However, a substantial increase of 29% was noted when confining pressure was increased to 35.0 MPa. The 100°C, 35.0 MPa test configuration yielded the highest modulus (75.45 GPa). Tests conducted at 200°C exhibited an 11% decrease in the modulus when confining pressure increased from 3.5 to 17.0 MPa and a 17% increase when confining pressure was increased from 17.0 to 35.0 MPa (Fig. 9). Data scatter can be seen in Fig. 10, 11 and 12.

The modulus behaved similarly for both constant confining pressures of 3.5 and 35.0 MPa and increasing temperature. At a confining pressure of 3.5 MPa, the modulus increased by 17% from 21° to 100°C and decreased by 6% from 100° to 200°C. The 35.0 MPa confining pressure results exhibited an increase of 18% and a decrease of 26% over the same temperature ranges. Measurements taken at a confining pressure of 17.0 MPa however, indicated constant decreases in modulus of 6% and 18% from 21° to 100°C and 100° to 200°C respectively (Fig. 13).

EFFECT OF TEMPERATURE ON COHESIVE STRENGTH AND ANGLE OF INTERNAL FRICTION

The cohesive strength determined at 3.5 MPa confining pressure was relatively insensitive to temperature change. On heating from 21° to 100°C the cohesive strength decreased by 7% and increased by 12% from 100° to 200°C. At 17.0 MPa confining pressure, the cohesive strength increased by 35% from 21° to 100°C and decreased by 12% on heating to 200°C. For tests carried out at a confining pressure of 35.0 MPa, the cohesive strength decreased by 15% from 21° to 100°C and increased by 31% from 100° to 200°C (Fig. 14).

As can be expected, the angle of internal friction exhibits the inverse of the behaviour of the cohesive strength. After heating from 21° to 100°C, the internal friction angle determined at 3.5 MPa confining pressure

increased by 5%. Further heating to 200°C resulted in a decrease of 3%. At a constant confining pressure of 17.0 MPa the angle of internal friction decreased by 11% from 21° to 100°C and increased by 6% from 100° to 200°C. Measurements carried out at 35.0 MPa confining pressure indicated a slight increase of 2% in the internal friction angle from 21° to 100°C. A considerably larger decrease of 16% resulted from subsequent heating to 200°C (Fig. 15).

REFERENCES

1. Nuclear Fuel Waste Disposal Program, Rock Property Activity Laboratory Task; Technical Report 8081-T2.

2. Annor, A., Miles, F., Kapeller, F. and Larocque, G. "High temperature and pressure triaxial compression tests on rock sample from Pinawa and Creighton Mines"; Technical Report 80-102(TR) ERP/MRL.

Confining Pressure σ_3 (MPa)	Internal Friction Angle ϕ	Cohesion C (MPa)	Failure Plane Angle θ	Failure Plane Stresses (MPa)	
				σ_θ	τ_θ
3.5	$\phi_1 = 60.0°$	$C_1 = 27$	$\theta_1 = 75.0°$	21	66
17.0	$\phi_2 = 57.0°$	$C_2 = 37$	$\theta_2 = 73.5°$	51	116
35.0	$\phi_3 = 44.0°$	$C_3 = 82$	$\theta_3 = 65.0°$	117	194

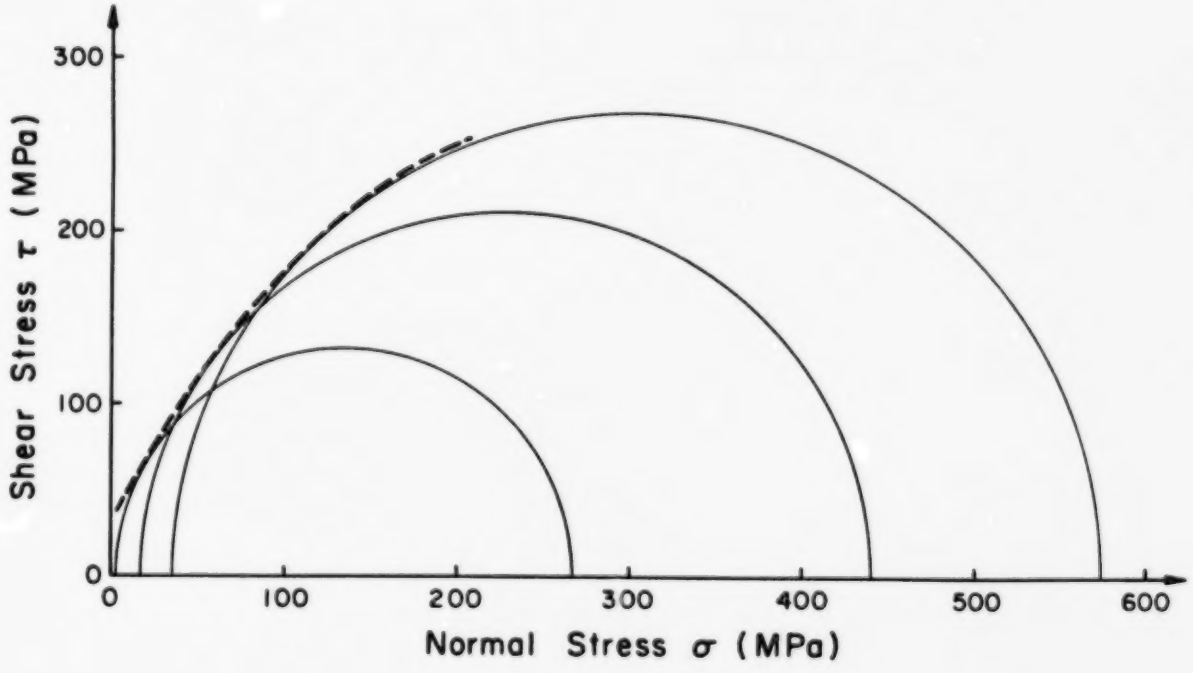

Fig. 1 - Mohr's circle and strength envelope: Atikokan Granite: 21°C.

Confining Pressure σ_3 (MPa)	Internal Friction Angle ϕ	Cohesion C (MPa)	Failure Plane Angle θ	Failure Plane Stresses (MPa)	
				σ_θ	τ_θ
3.5	$\phi_1 = 63.0°$	$C_1 = 25$	$\theta_1 = 76.5°$	18	60
17.0	$\phi_2 = 51.0°$	$C_2 = 50$	$\theta_2 = 70.5°$	63	129
35.0	$\phi_3 = 45.0°$	$C_3 = 70$	$\theta_3 = 67.5°$	110	182

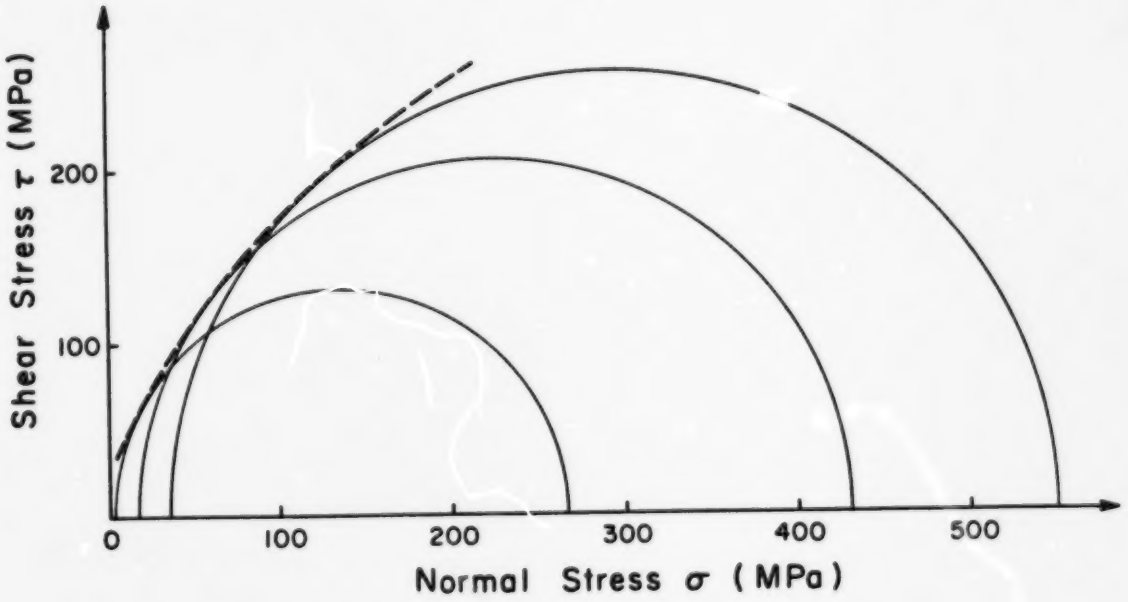

Fig. 2 - Mohr's circle and strength envelope: Atikokan Granite: 100°C.

Confining Pressure σ_3 (MPa)	Internal Friction Angle ϕ	Cohesion C (MPa)	Failure Plane Angle θ	Failure Plane Stresses (MPa)	
				σ_θ	τ_θ
3.5	$\phi_1 = 61.0°$	$C_1 = 28$	$\theta_1 = 75.5°$	20	64
17.0	$\phi_2 = 54.0°$	$C_2 = 44$	$\theta_2 = 72.0°$	56	119
35.0	$\phi_3 = 38.0°$	$C_3 = 92$	$\theta_3 = 64.0°$	130	195

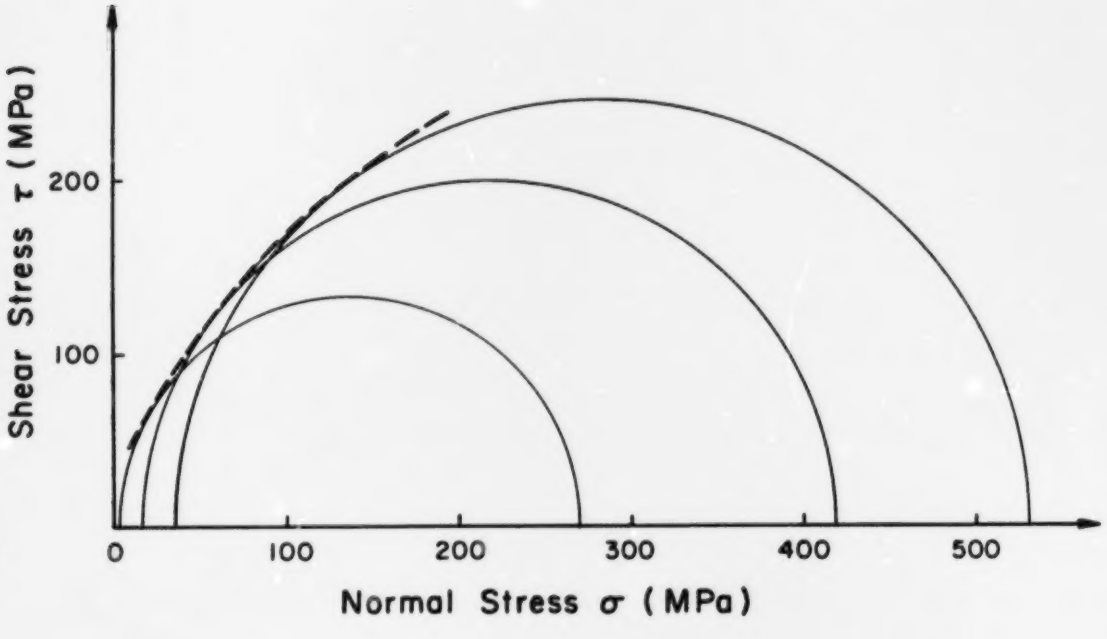

Fig. 3 - Mohr's circle and strength envelope: Atikokan Granite: 200°C.

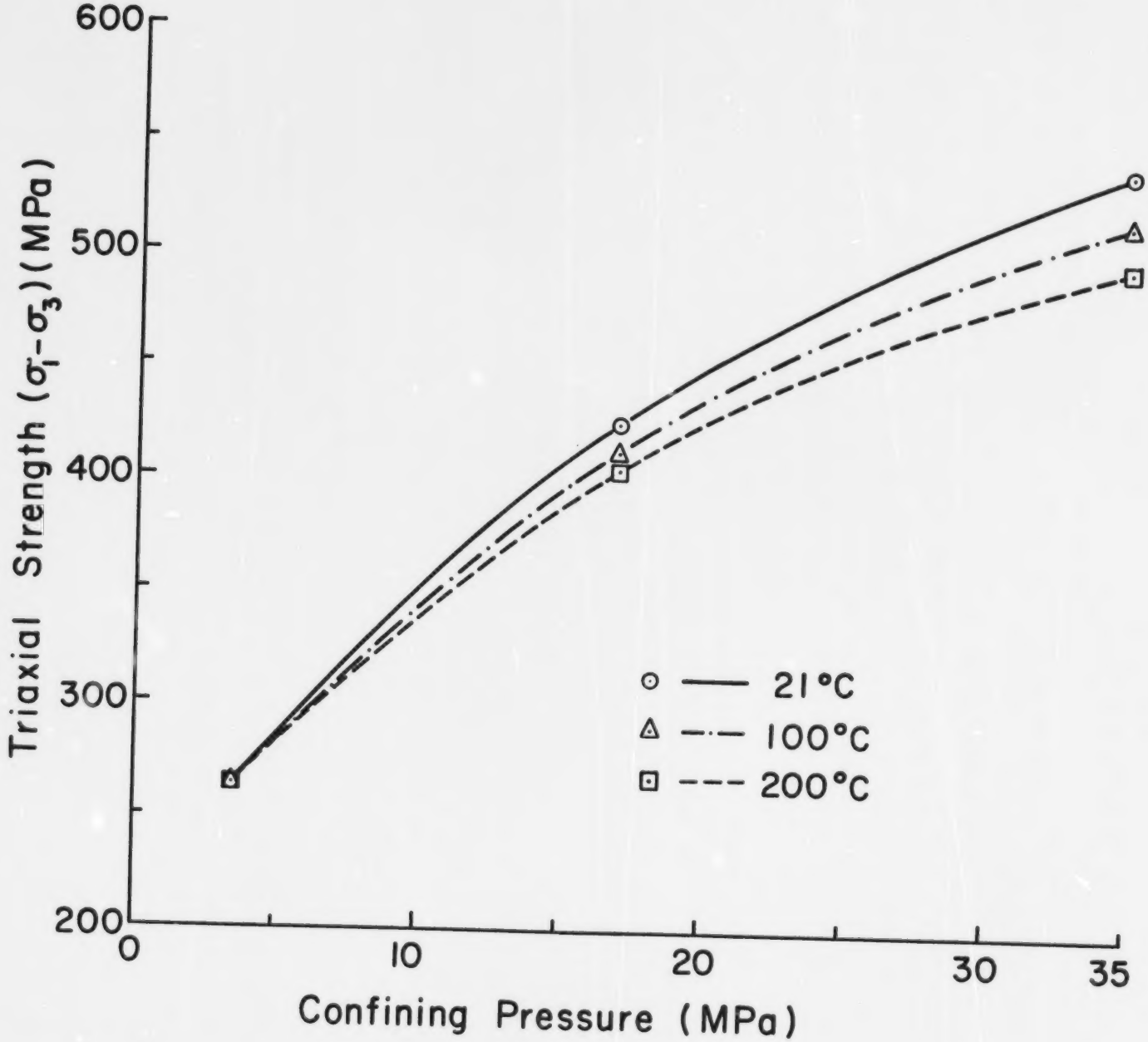

Fig. 4 - Triaxial strength vs confining pressure: Atikokan Granite.

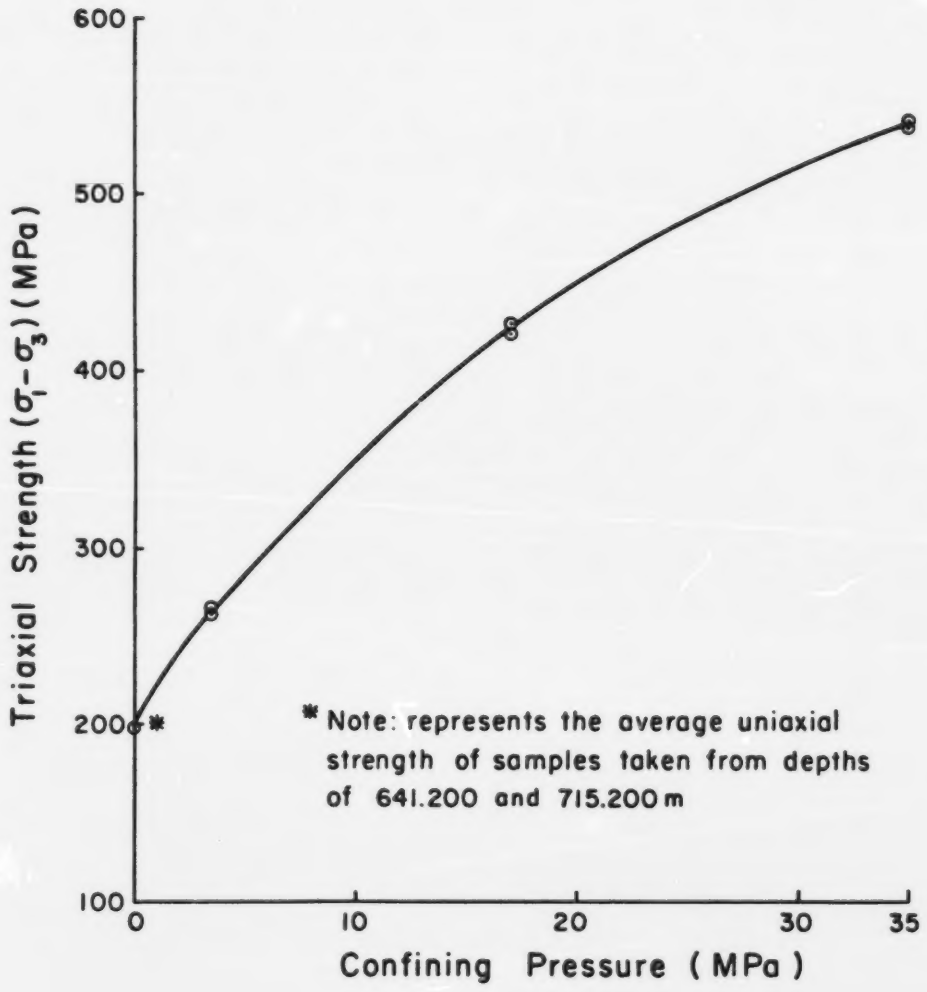

Fig. 5 - Triaxial strength vs confining pressure: Atikokan Granite: 21°C

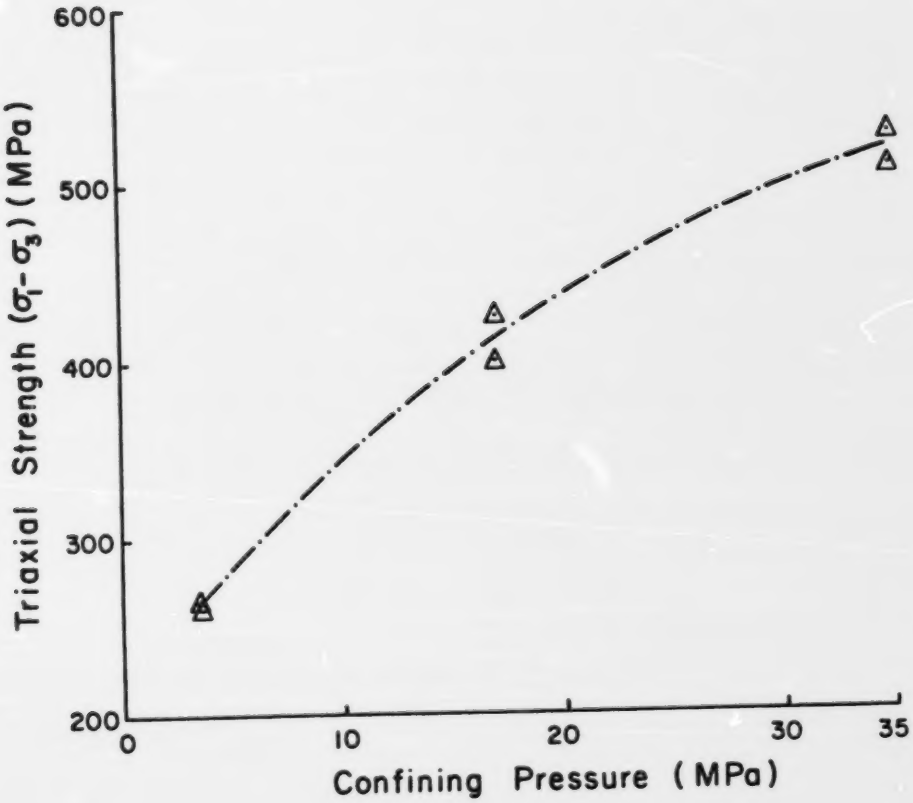

Fig. 6 - Triaxial strength vs confining pressure: Atikokan Granite: 100°C.

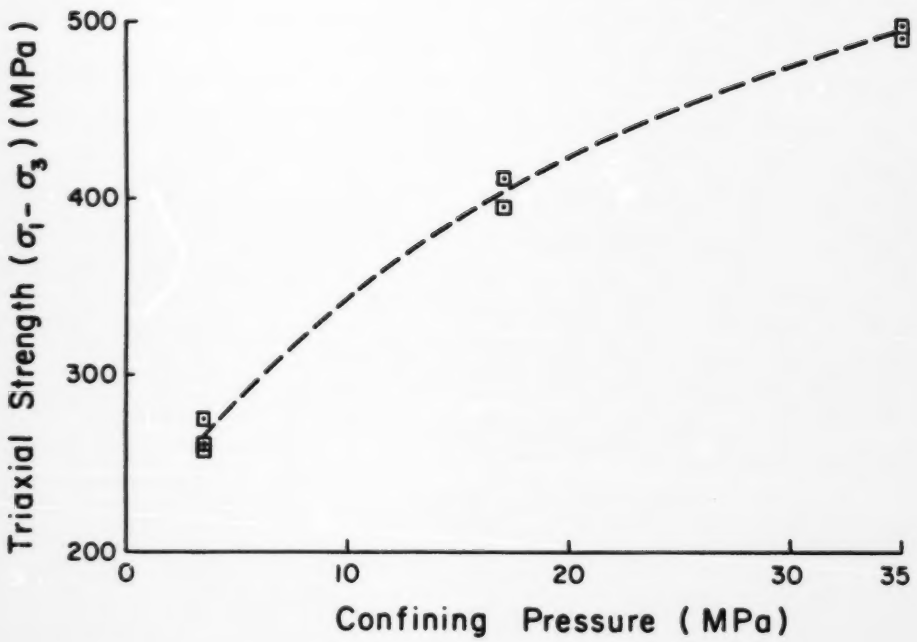

Fig. 7 - Triaxial strength vs confining pressure: Atikokan Granite: 200°C.

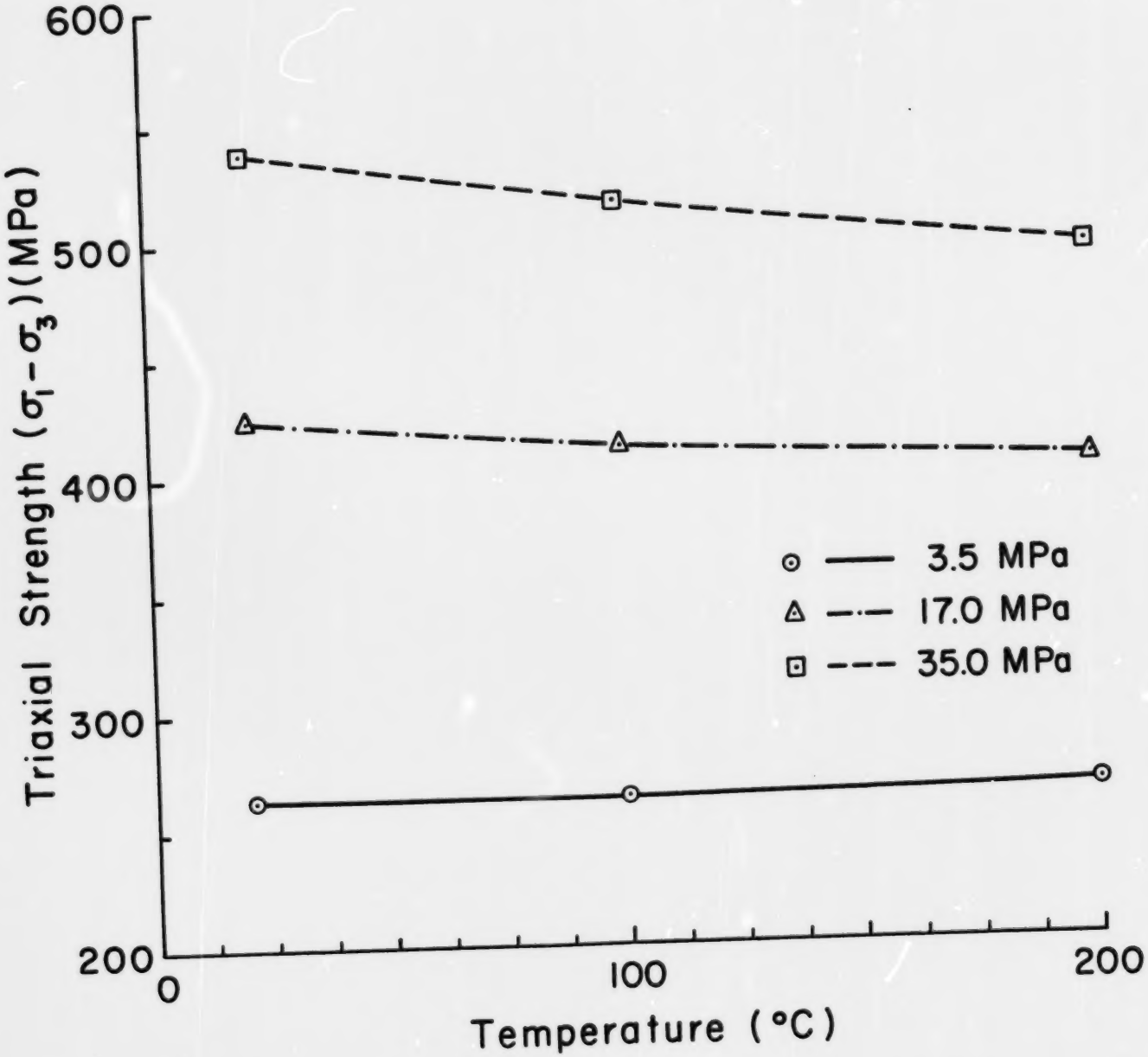

Fig. 8 - Triaxial strength vs confining pressure: Atikokan Granite.

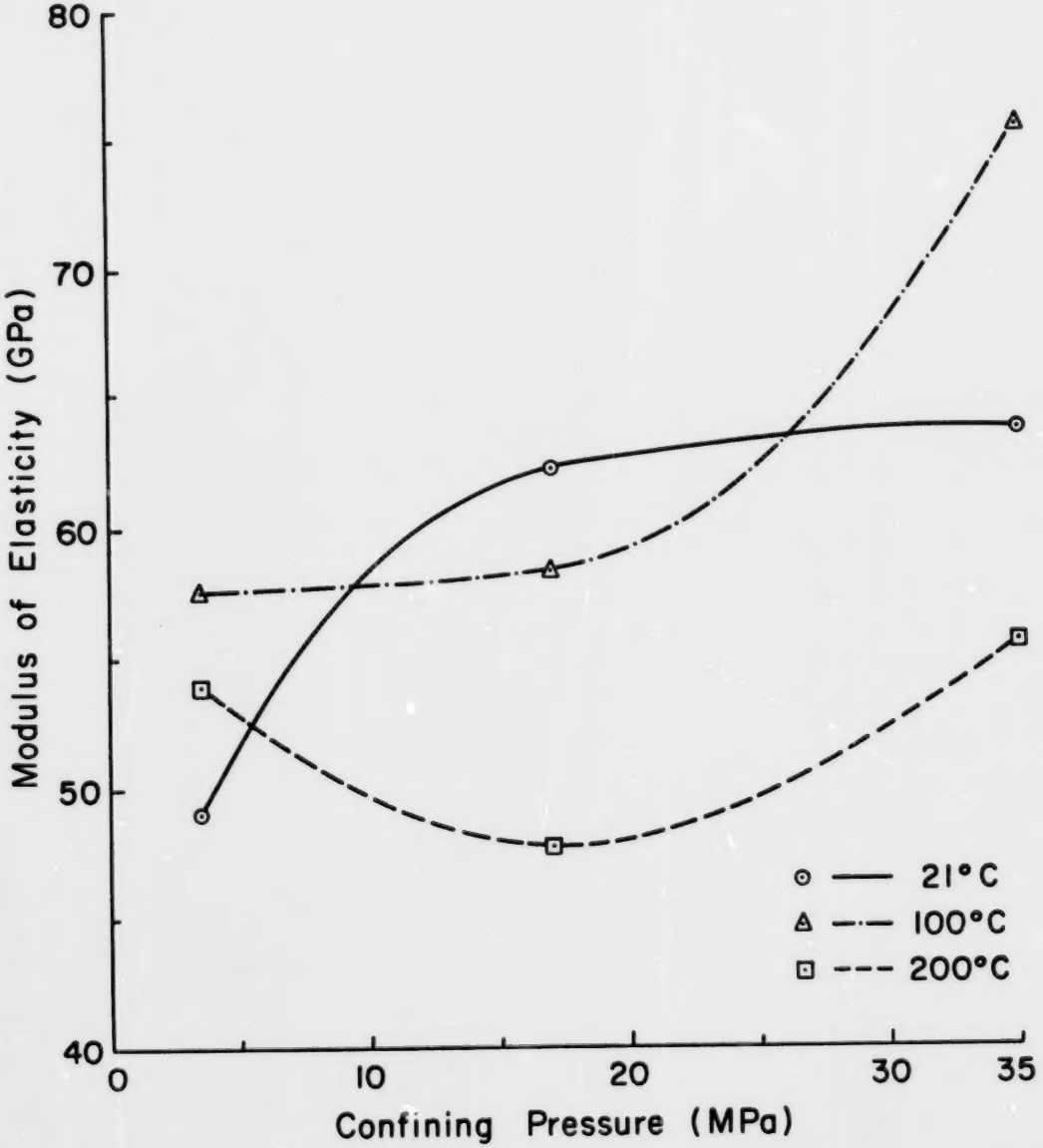

Fig. 9 - Tangent modulus of elasticity vs confining pressure: Atikokan Granite.

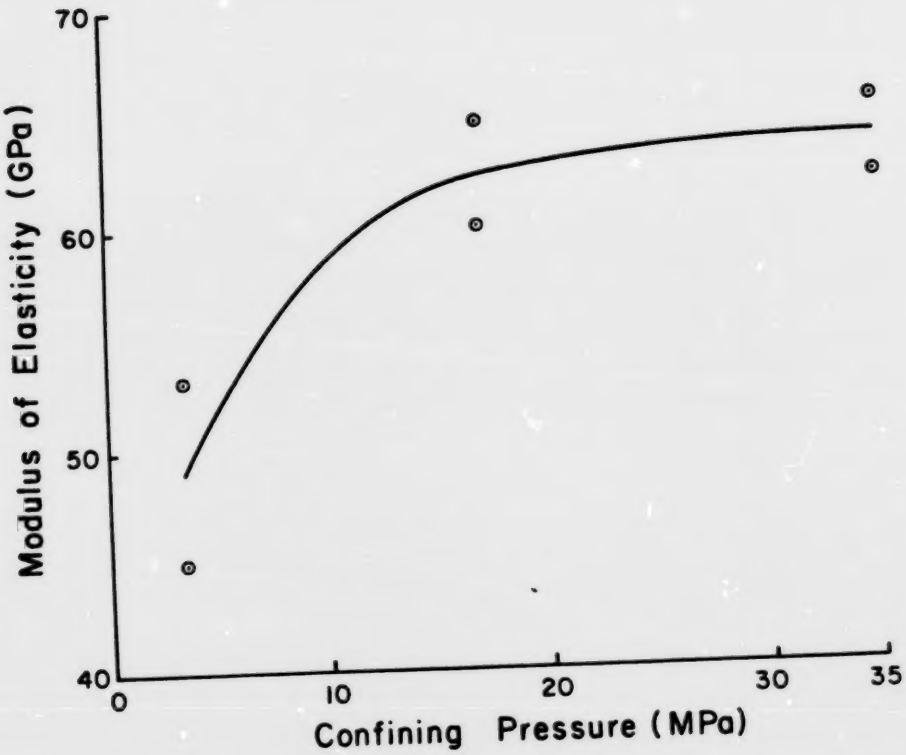

Fig. 10 - Tangent modulus of elasticity vs confining pressure: Atikokan Granite: 21°C.

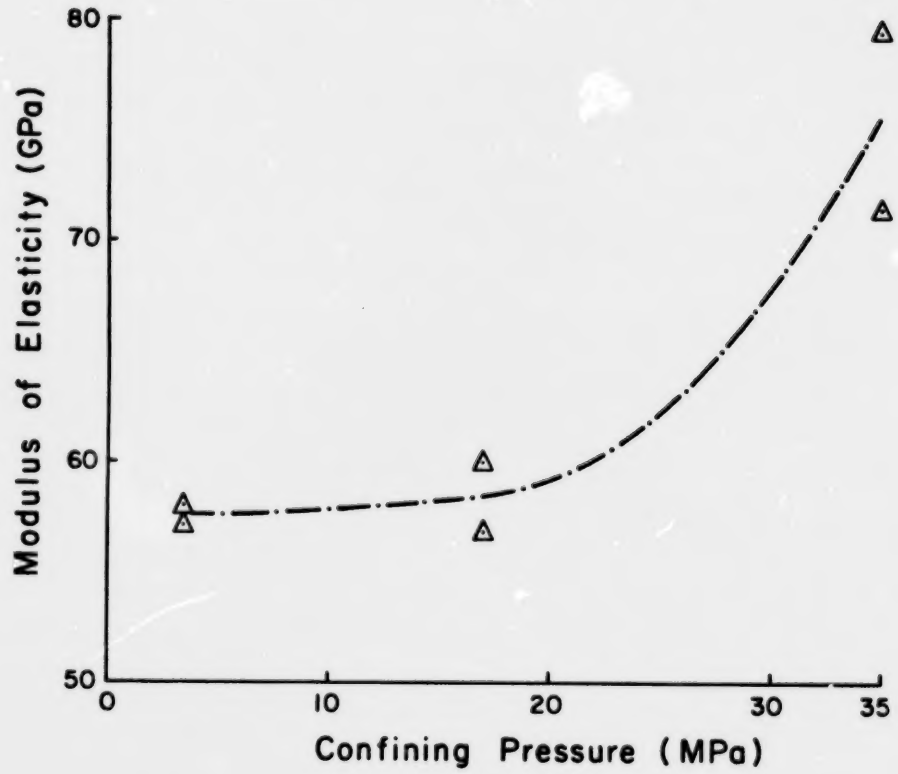

Fig. 11 - Tangent modulus of elasticity vs confining pressure: Atikokan Granite: 100°C.

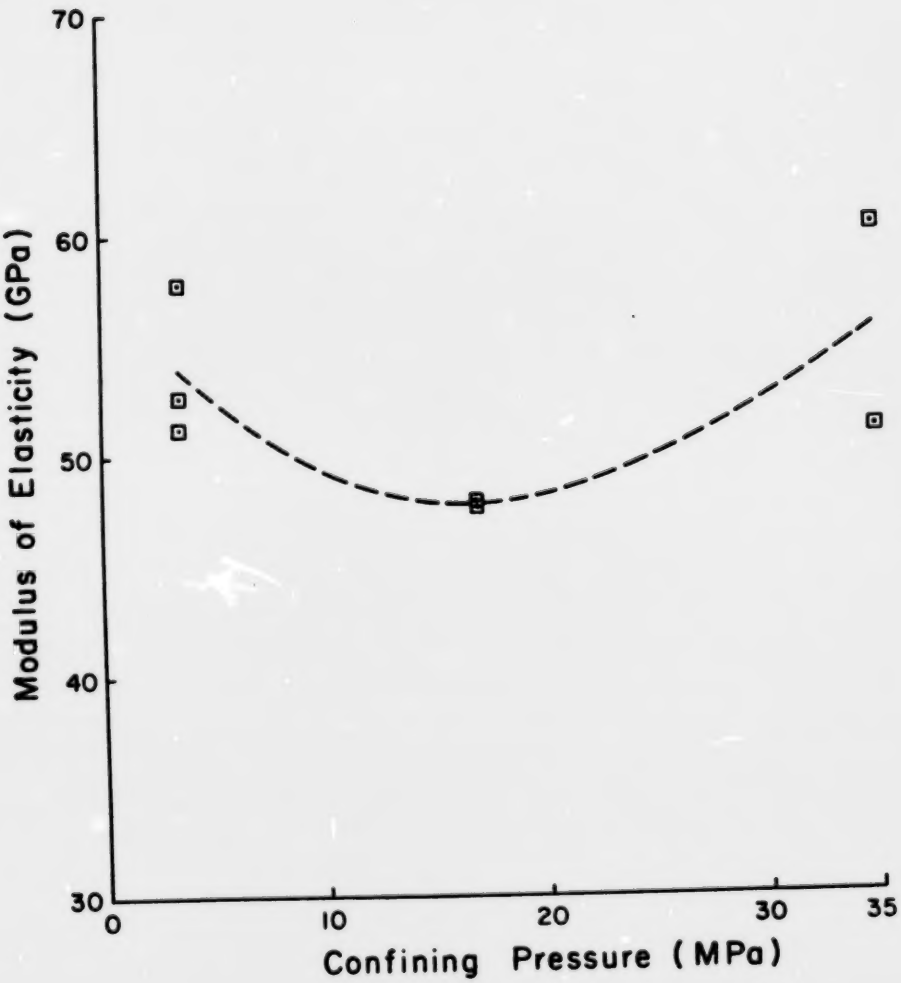

Fig. 12 - Tangent modulus of elasticity vs confining pressure: Atikokan Granite: 200°C.

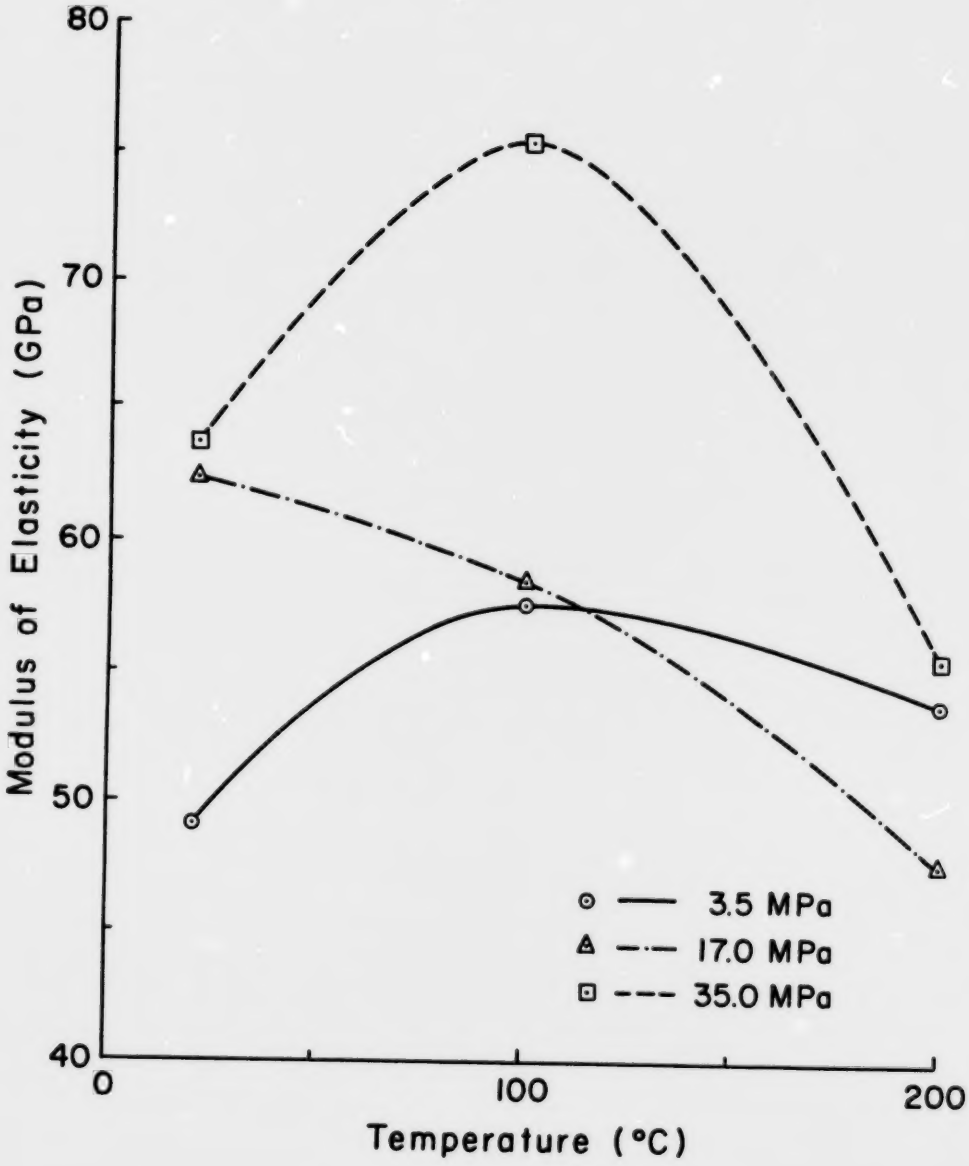

Fig. 13 - Tangent modulus of elasticity vs temperature: Atikokan Granite.

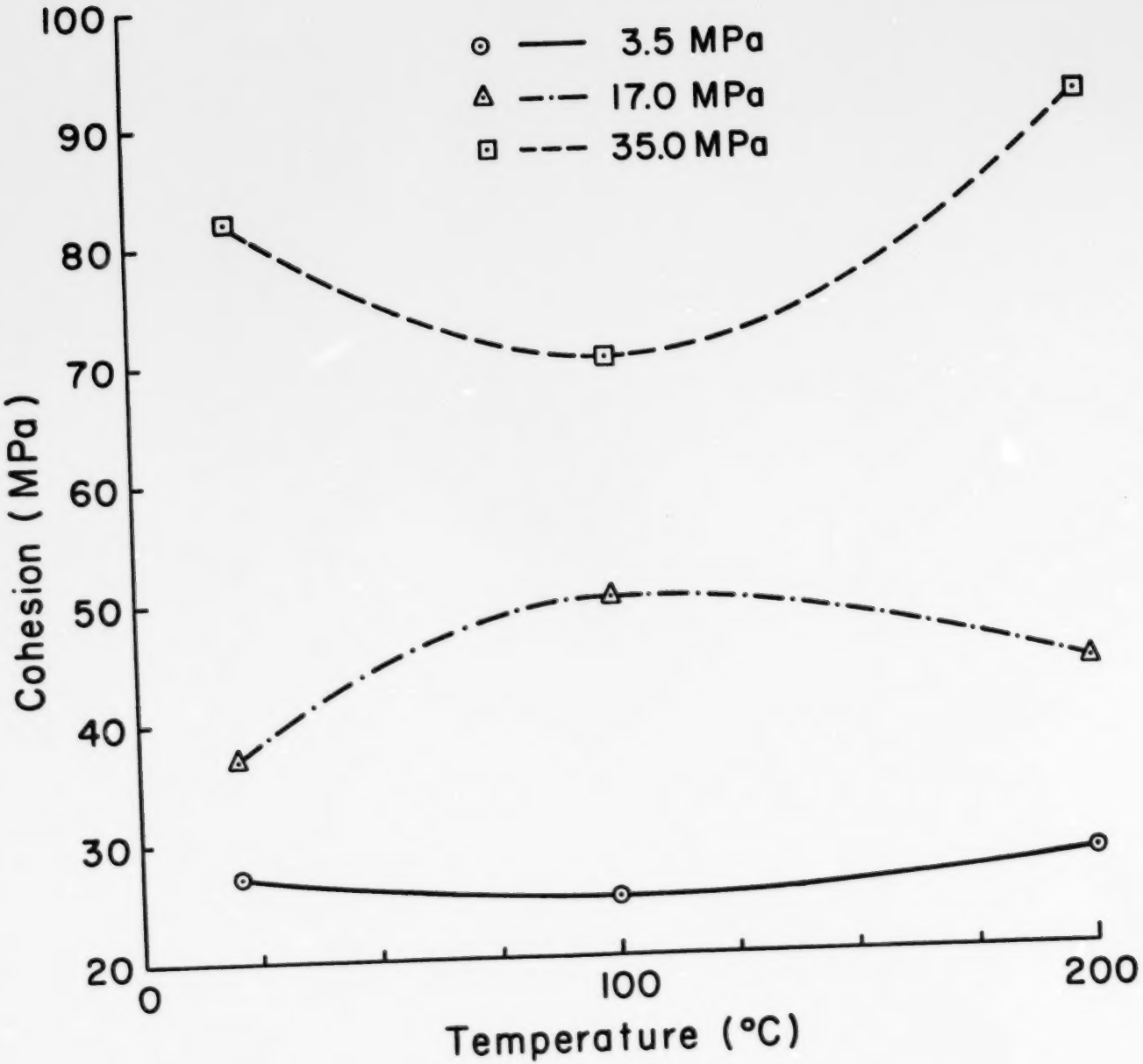

Fig. 14 - Cohesive strength vs temperature: Atikokan Granite.

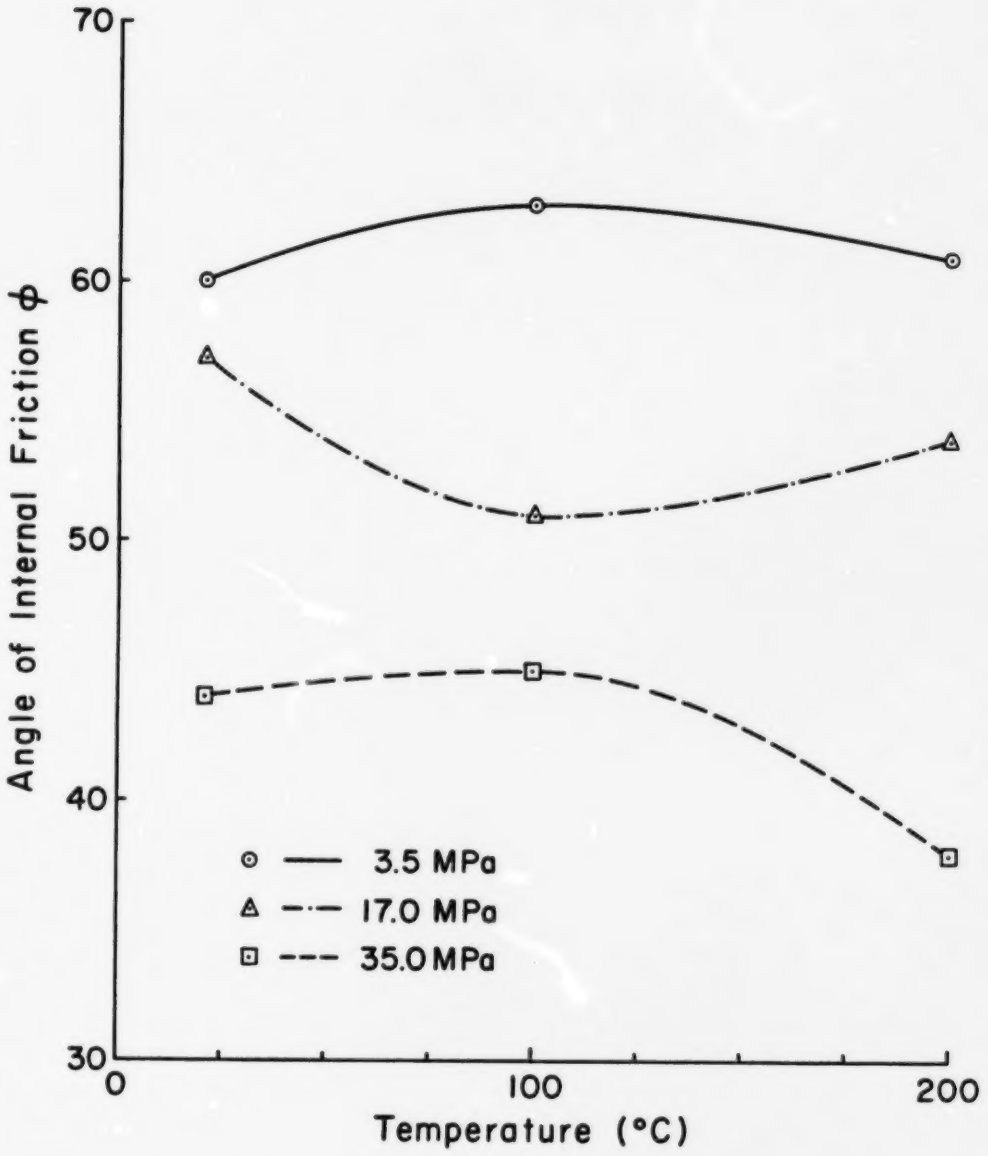

Fig. 15 - Angle of internal friction vs temperature: Atikokan Granite.